FIG. 1

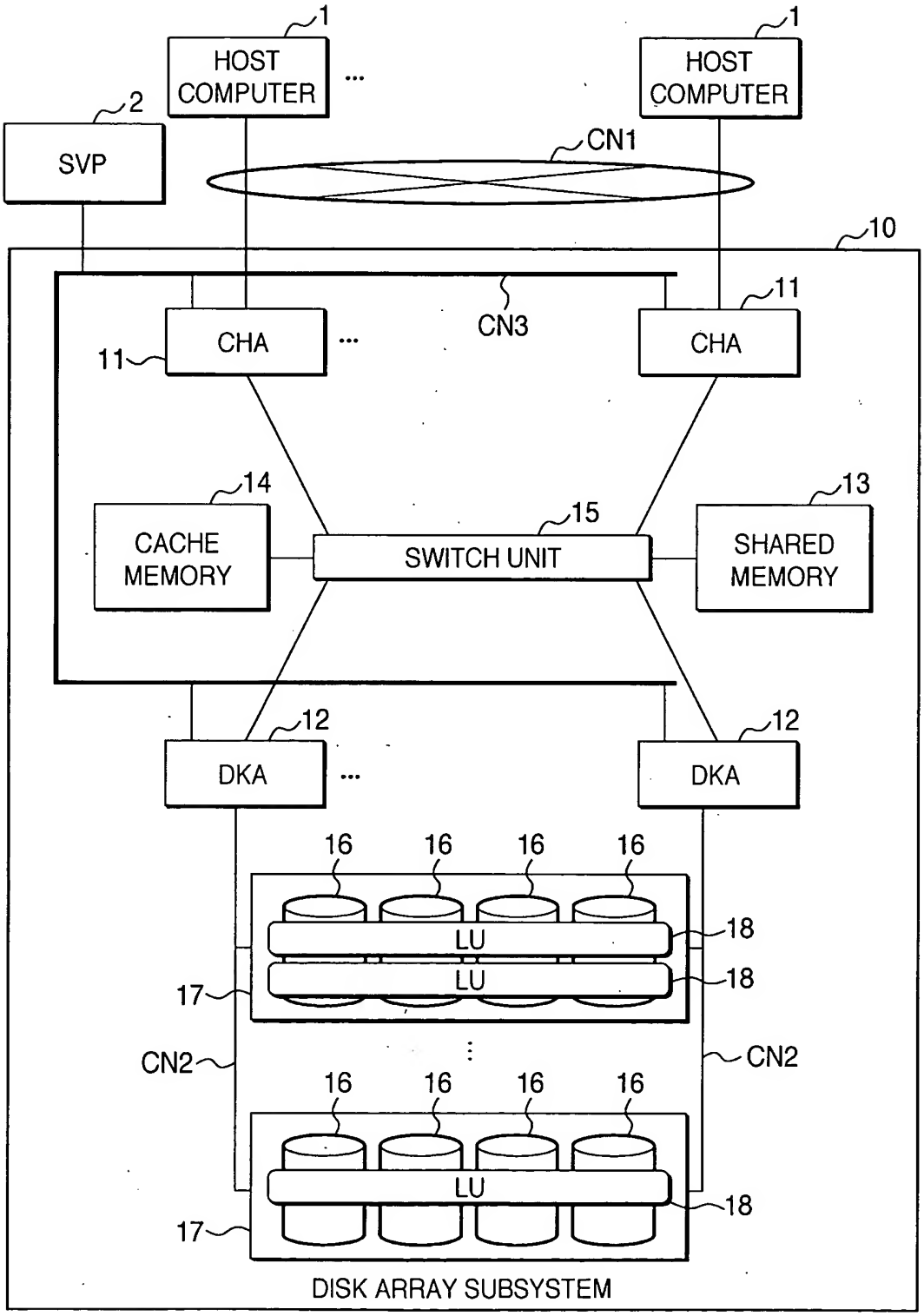
1
HOST COMPUTER
1
HOST COMPUTER
2
SVP
CN1
10
CN3
11
CHA
11
CHA
14
CACHE MEMORY
15
SWITCH UNIT
13
SHARED MEMORY
12
DKA
12
DKA
16
16
16
16
LU
18
LU
18
17
CN2
CN2
16
16
16
16
LU
18
17
DISK ARRAY SUBSYSTEM

FIG. 2A

T1

GROUP#	VOLUME#	DISK#	RAID LEVEL
1	1, 2, 3	1, 2, 3, 4	RAID5
2	4, 5, 6	5, 6, 7, 8	RAID5
3	7, 8, 9, 10	9, 10, 11, 12	RAID1
4	11, 12	13, 14, 15, 16	RAID1
5	NULL	17, 18, 19, 20	RAID5
⋮	⋮	⋮	⋮

FIG. 2B

T1

GROUP#	VOLUME#	DISK#	RAID LEVEL
1	1, 2, 3	1, 2, 3, 4	RAID5
2	4, 5, 6	5, 6, 7, 8	RAID5
3	7, 8, 9, 10	9, 10, 11, 12	RAID1
4	11, 12	13, 14, 15, 16	RAID1
5	13, 14, 15	17, 18, 19, 20	RAID5
⋮	⋮	⋮	⋮

FIG. 3A

T2

PRIMARY VOLUME#	SECONDARY VOLUME#	PAIRING STATUS	DIFFERENTIAL BITMAP
4	7	DUPLEX	010000100000···
5	8	DUPLEX	100000010000···

FIG. 3B

T2

PRIMARY VOLUME#	SECONDARY VOLUME#	PAIRING STATUS	DIFFERENTIAL BITMAP
4	7	DUPLEX	010000100000···
5	8	DUPLEX	100000010000···
1	13	UPDATE DATA BEING BACKED UP	110000100011···
2	14	UPDATE DATA BEING BACKED UP	100001000000···
3	15	UPDATE DATA BEING BACKED UP	000000000000···

FIG. 4A

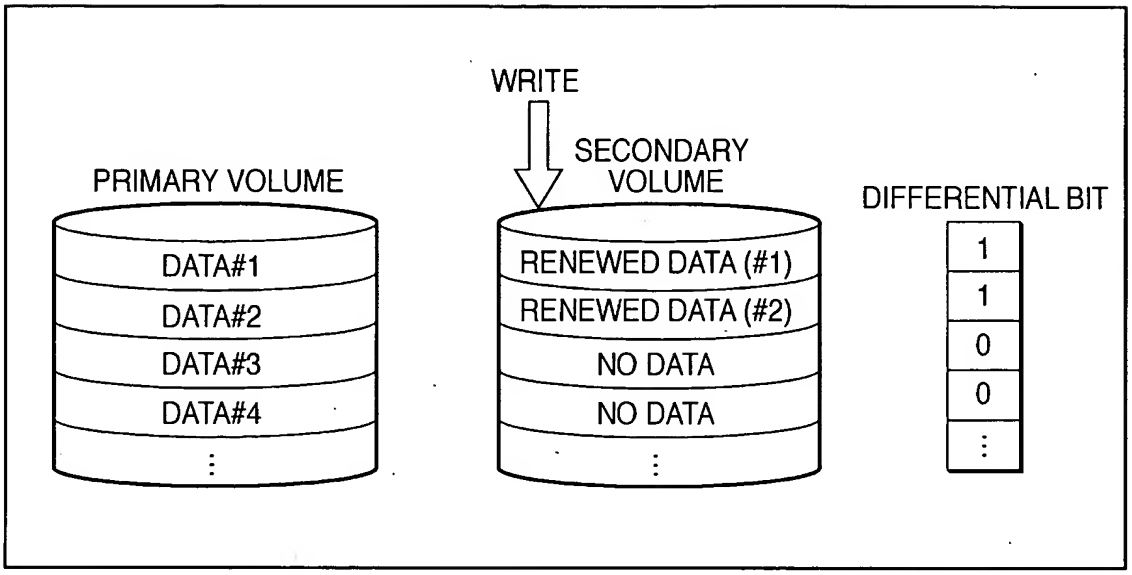
WRITE
PRIMARY VOLUME
SECONDARY VOLUME
DIFFERENTIAL BIT
DATA#1
DATA#2
DATA#3
DATA#4
RENEWED DATA (#1)
RENEWED DATA (#2)
NO DATA
NO DATA
1
1
0
0

FIG. 4B

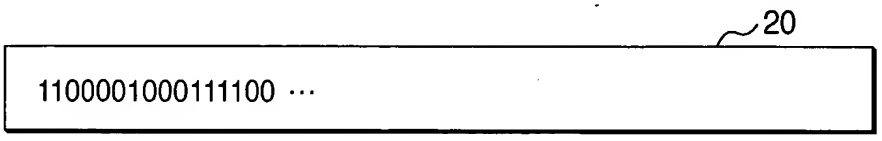
20
1100001000111100 ···

FIG. 5

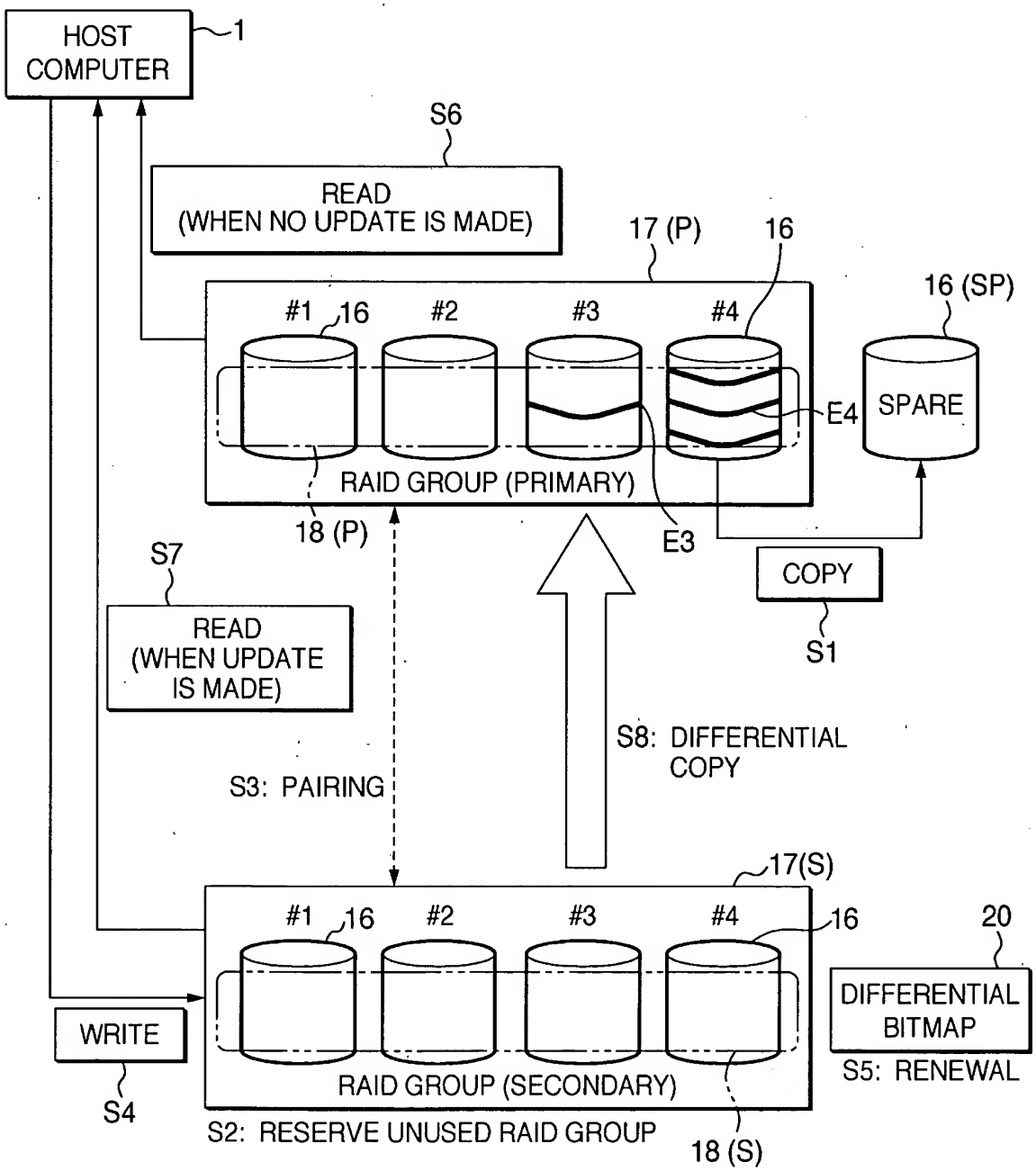
HOST COMPUTER
1
S6
READ (WHEN NO UPDATE IS MADE)
17 (P)
16
16 (SP)
#1
16
#2
#3
#4
E4
SPARE
RAID GROUP (PRIMARY)
18 (P)
E3
S7
READ (WHEN UPDATE IS MADE)
COPY
S1
S8: DIFFERENTIAL COPY
S3: PAIRING
17(S)
#1
16
#2
#3
#4
16
20
DIFFERENTIAL BITMAP
S5: RENEWAL
WRITE
S4
RAID GROUP (SECONDARY)
S2: RESERVE UNUSED RAID GROUP
18 (S)

FIG. 6

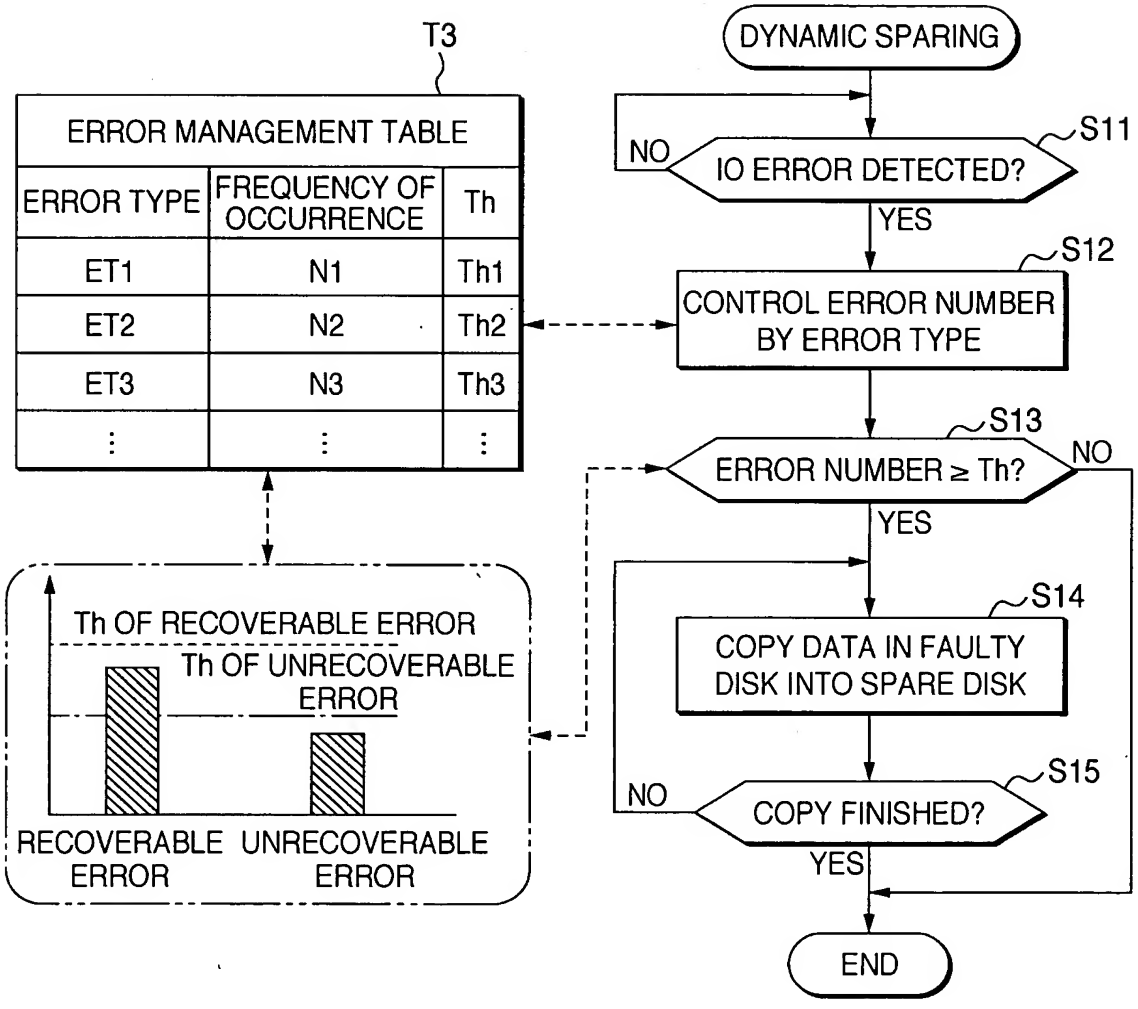
T3
ERROR MANAGEMENT TABLE
ERROR TYPE
FREQUENCY OF OCCURRENCE
Th
ET1
N1
Th1
ET2
N2
Th2
ET3
N3
Th3
Th OF RECOVERABLE ERROR
Th OF UNRECOVERABLE ERROR
RECOVERABLE ERROR
UNRECOVERABLE ERROR
DYNAMIC SPARING
S11
NO
IO ERROR DETECTED?
YES
S12
CONTROL ERROR NUMBER BY ERROR TYPE
S13
ERROR NUMBER ≥ Th?
NO
YES
S14
COPY DATA IN FAULTY DISK INTO SPARE DISK
S15
NO
COPY FINISHED?
YES
END

FIG. 7

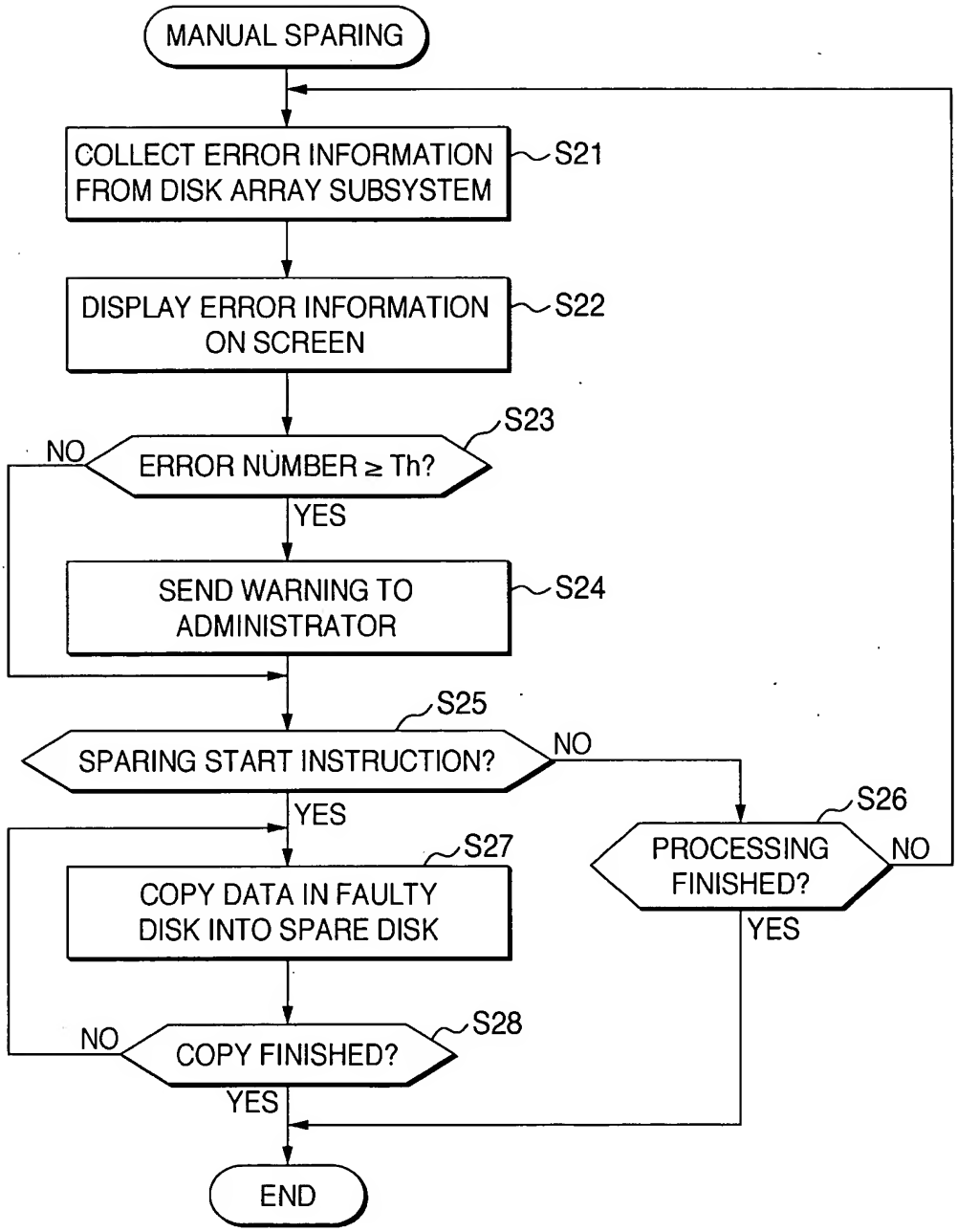
MANUAL SPARING
COLLECT ERROR INFORMATION FROM DISK ARRAY SUBSYSTEM
S21
DISPLAY ERROR INFORMATION ON SCREEN
S22
S23
NO
ERROR NUMBER ≥ Th?
YES
SEND WARNING TO ADMINISTRATOR
S24
S25
SPARING START INSTRUCTION?
NO
YES
S26
PROCESSING FINISHED?
NO
YES
S27
COPY DATA IN FAULTY DISK INTO SPARE DISK
S28
NO
COPY FINISHED?
YES
END

FIG. 8

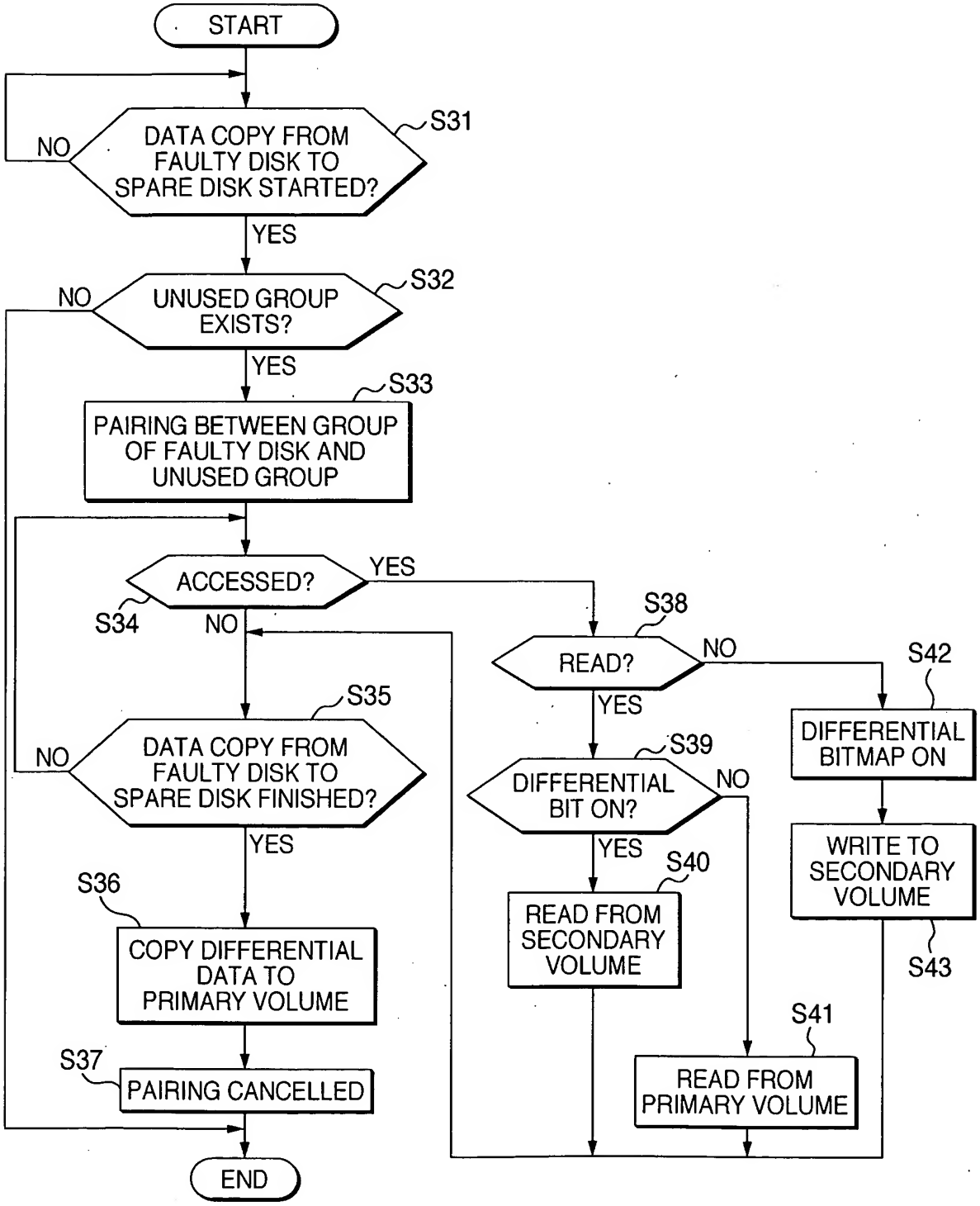
START
DATA COPY FROM FAULTY DISK TO SPARE DISK STARTED?
S31
NO
YES
UNUSED GROUP EXISTS?
S32
NO
YES
PAIRING BETWEEN GROUP OF FAULTY DISK AND UNUSED GROUP
S33
ACCESSED?
YES
S34
NO
S38
READ?
NO
S42
YES
DIFFERENTIAL BITMAP ON
S35
DATA COPY FROM FAULTY DISK TO SPARE DISK FINISHED?
NO
S39
DIFFERENTIAL BIT ON?
NO
YES
S40
WRITE TO SECONDARY VOLUME
S43
YES
S36
READ FROM SECONDARY VOLUME
COPY DIFFERENTIAL DATA TO PRIMARY VOLUME
S41
S37
READ FROM PRIMARY VOLUME
PAIRING CANCELLED
END

FIG. 9

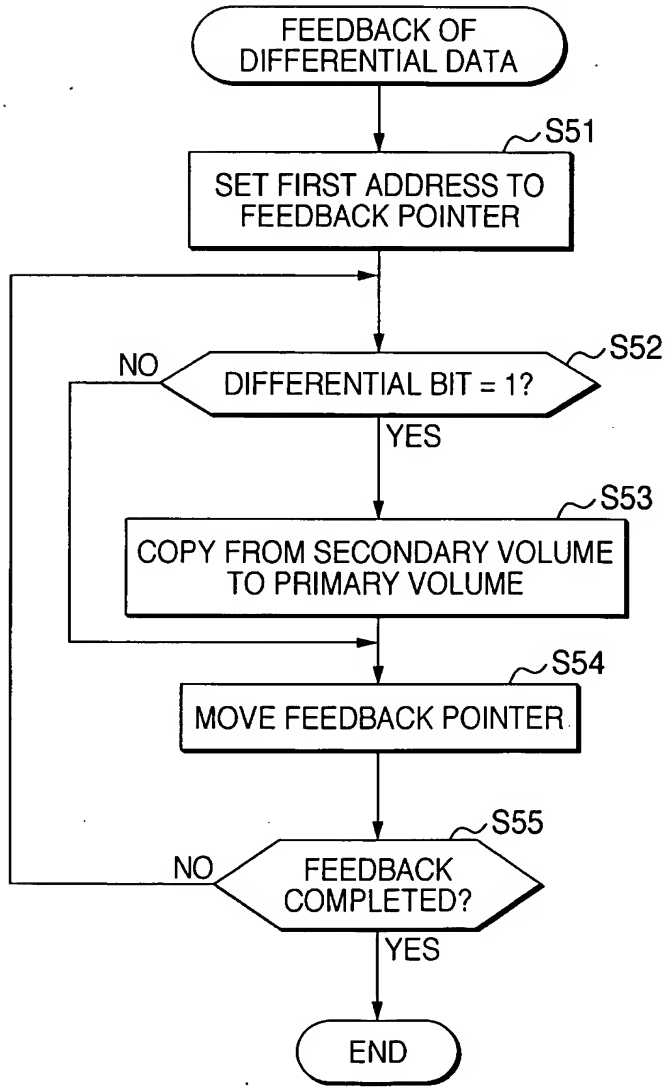
FEEDBACK OF DIFFERENTIAL DATA
S51
SET FIRST ADDRESS TO FEEDBACK POINTER
S52
NO
DIFFERENTIAL BIT = 1?
YES
S53
COPY FROM SECONDARY VOLUME TO PRIMARY VOLUME
S54
MOVE FEEDBACK POINTER
S55
NO
FEEDBACK COMPLETED?
YES
END

FIG. 10

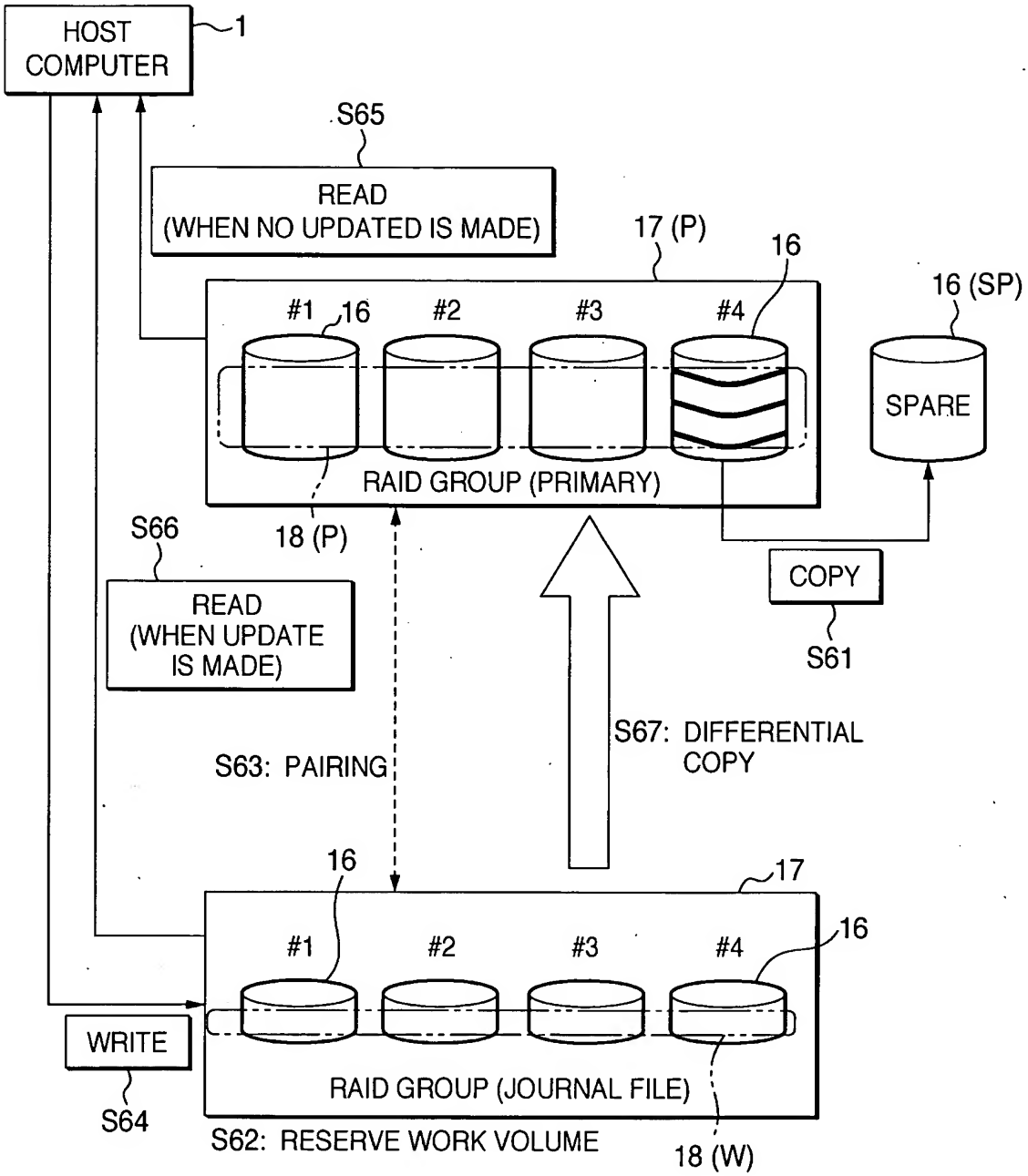
HOST COMPUTER
1
S65
READ (WHEN NO UPDATED IS MADE)
17 (P)
16
16 (SP)
#1
16
#2
#3
#4
SPARE
RAID GROUP (PRIMARY)
18 (P)
S66
READ (WHEN UPDATE IS MADE)
COPY
S61
S67: DIFFERENTIAL COPY
S63: PAIRING
16
17
16
#1
#2
#3
#4
WRITE
S64
RAID GROUP (JOURNAL FILE)
S62: RESERVE WORK VOLUME
18 (W)

FIG. 11A

T4

WORK VOLUME#	CAPACITY	PRIMARY VOLUME#	TERMINAL ADDRESS	DIFFERENTIAL BITMAP
10	3GB	NULL	NULL	0000000000···
11	3GB	NULL	NULL	0000000000···
12	3GB	NULL	NULL	0000000000···

FIG. 11B

T4

WORK VOLUME#	CAPACITY	PRIMARY VOLUME#	TERMINAL ADDRESS	DIFFERENTIAL BITMAP
10	3GB	1	3	1110000000···
11	3GB	2	NULL	0000000000···
12	3GB	3	NULL	0000000000···

FIG. 11C

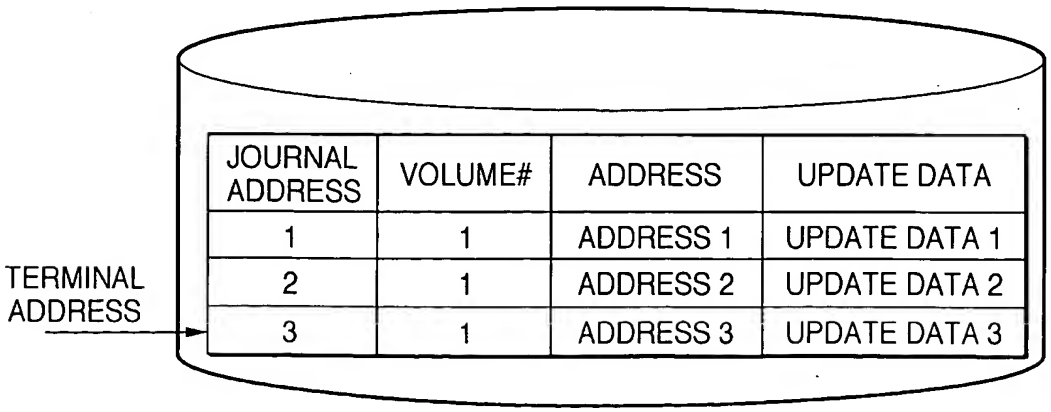

FIG. 12

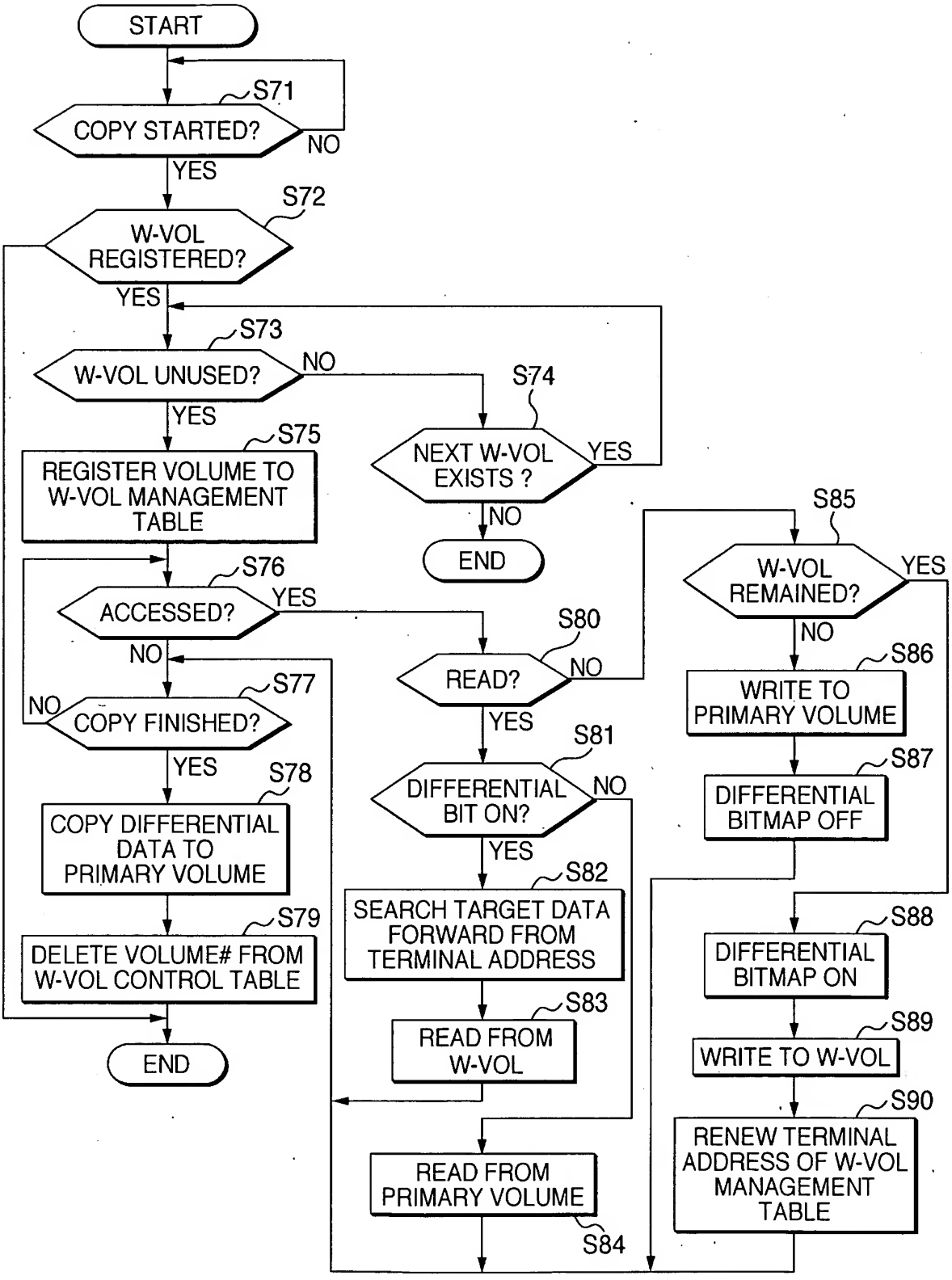
START
S71
COPY STARTED?
NO
YES
S72
W-VOL REGISTERED?
YES
S73
W-VOL UNUSED?
NO
S74
NEXT W-VOL EXISTS ?
YES
NO
END
YES
S75
REGISTER VOLUME TO W-VOL MANAGEMENT TABLE
S76
ACCESSED?
YES
NO
S77
NO
COPY FINISHED?
YES
S78
COPY DIFFERENTIAL DATA TO PRIMARY VOLUME
S79
DELETE VOLUME# FROM W-VOL CONTROL TABLE
END
S80
READ?
NO
YES
S81
DIFFERENTIAL BIT ON?
NO
YES
S82
SEARCH TARGET DATA FORWARD FROM TERMINAL ADDRESS
S83
READ FROM W-VOL
READ FROM PRIMARY VOLUME
S84
S85
W-VOL REMAINED?
YES
NO
S86
WRITE TO PRIMARY VOLUME
S87
DIFFERENTIAL BITMAP OFF
S88
DIFFERENTIAL BITMAP ON
S89
WRITE TO W-VOL
S90
RENEW TERMINAL ADDRESS OF W-VOL MANAGEMENT TABLE

FIG. 13

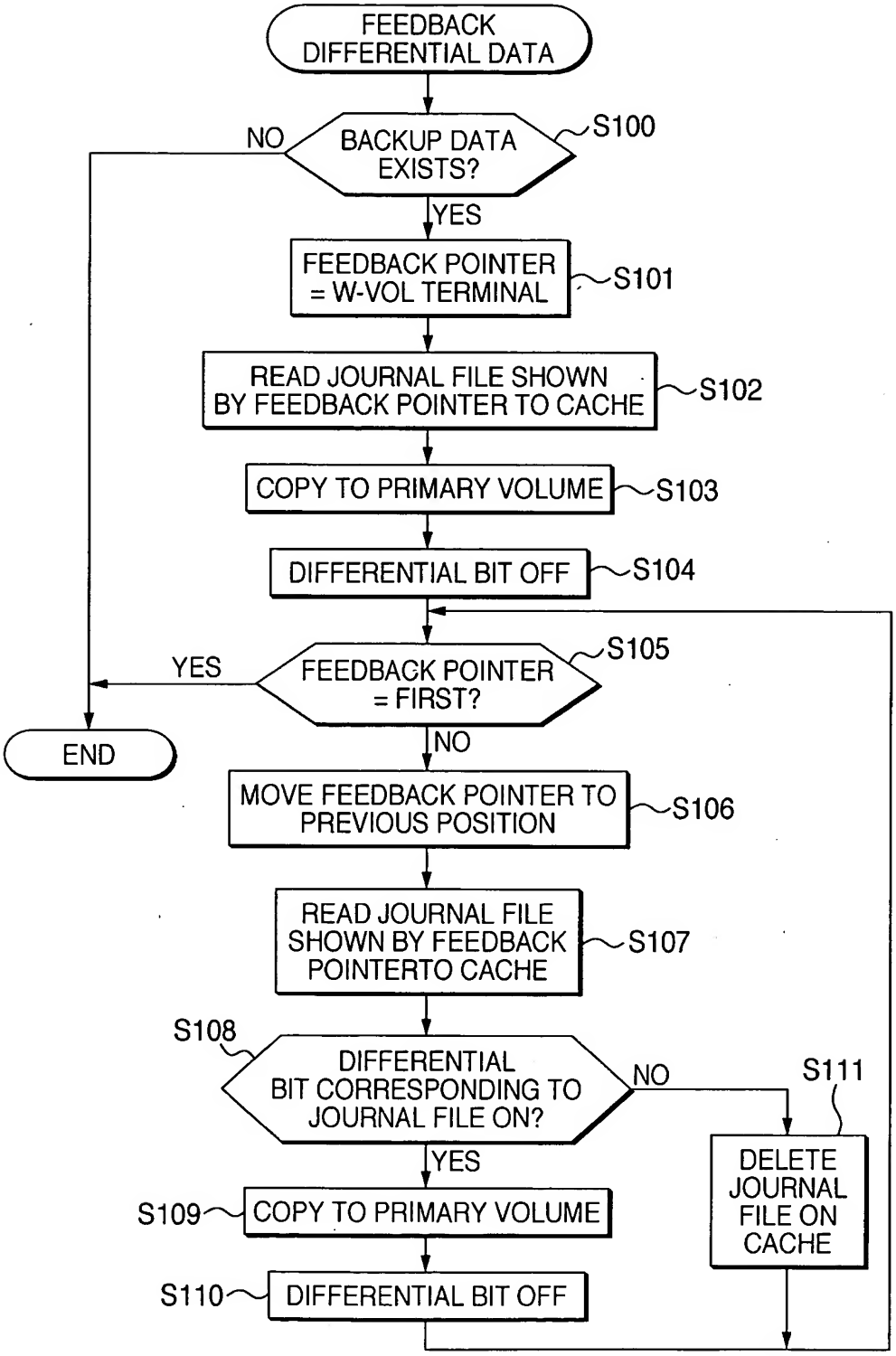
FEEDBACK DIFFERENTIAL DATA
BACKUP DATA EXISTS?
S100
NO
YES
FEEDBACK POINTER = W-VOL TERMINAL
S101
READ JOURNAL FILE SHOWN BY FEEDBACK POINTER TO CACHE
S102
COPY TO PRIMARY VOLUME
S103
DIFFERENTIAL BIT OFF
S104
FEEDBACK POINTER = FIRST?
S105
YES
NO
END
MOVE FEEDBACK POINTER TO PREVIOUS POSITION
S106
READ JOURNAL FILE SHOWN BY FEEDBACK POINTERTO CACHE
S107
S108
DIFFERENTIAL BIT CORRESPONDING TO JOURNAL FILE ON?
NO
S111
YES
DELETE JOURNAL FILE ON CACHE
S109
COPY TO PRIMARY VOLUME
S110
DIFFERENTIAL BIT OFF

FIG. 14

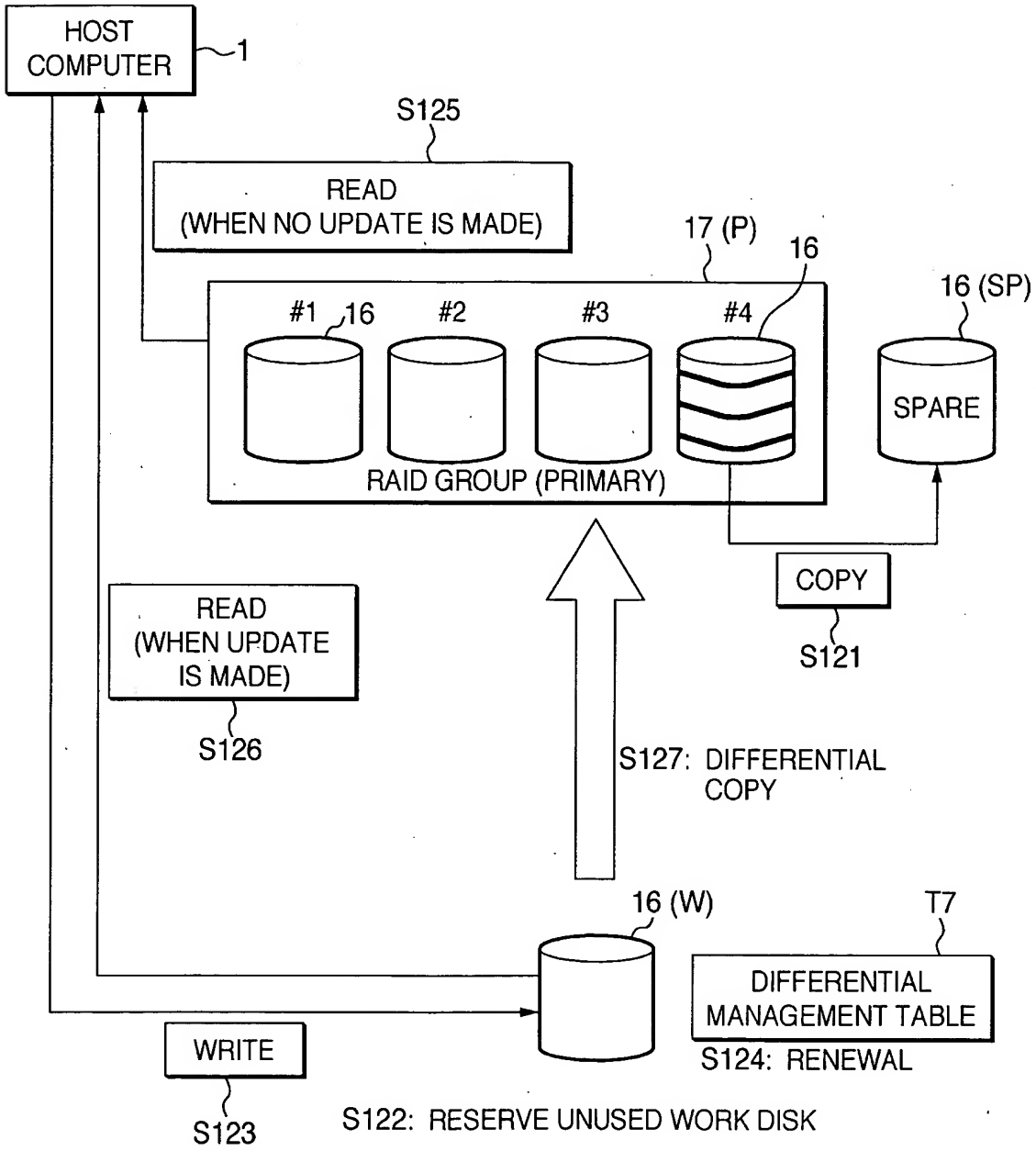
HOST COMPUTER
1
S125
READ (WHEN NO UPDATE IS MADE)
17 (P)
16
16 (SP)
#1
16
#2
#3
#4
SPARE
RAID GROUP (PRIMARY)
COPY
S121
READ (WHEN UPDATE IS MADE)
S126
S127: DIFFERENTIAL COPY
16 (W)
T7
DIFFERENTIAL MANAGEMENT TABLE
S124: RENEWAL
WRITE
S123
S122: RESERVE UNUSED WORK DISK

FIG. 15A

T5

DISK#	CAPACITY	STATUS
1	18GB	RENEWED DATA BEING BACKED UP
2	18GB	RENEWED DATA BEING BACKED UP
3	18GB	RENEWED DATA BEING BACKED UP
4	18GB	RENEWED DATA BEING BACKED UP
5	18GB	NULL
⋮	⋮	⋮

FIG. 15B

T6

DISK#	CAPACITY	STATUS	MAIN DISK#	TERMINAL ADDRESS
60	18GB	UNUSED	NULL	NULL
61	18GB	UNUSED	NULL	NULL

FIG. 15C

T6

DISK#	CAPACITY	STATUS	MAIN DISK#	TERMINAL ADDRESS
60	18GB	IN USE	1, 2, 3, 4	6
61	18GB	UNUSED	NULL	NULL

FIG. 16

T7

MAIN DISK#	MAIN DISK ADDRESS	WORK DISK#	WORK DISK ADDRESS
1	1	60	1
1	2	60	2
2	5	60	3
2	2	60	4
2	6	60	5
3	3	60	6

TERMINAL ADDRESS →

FIG. 17

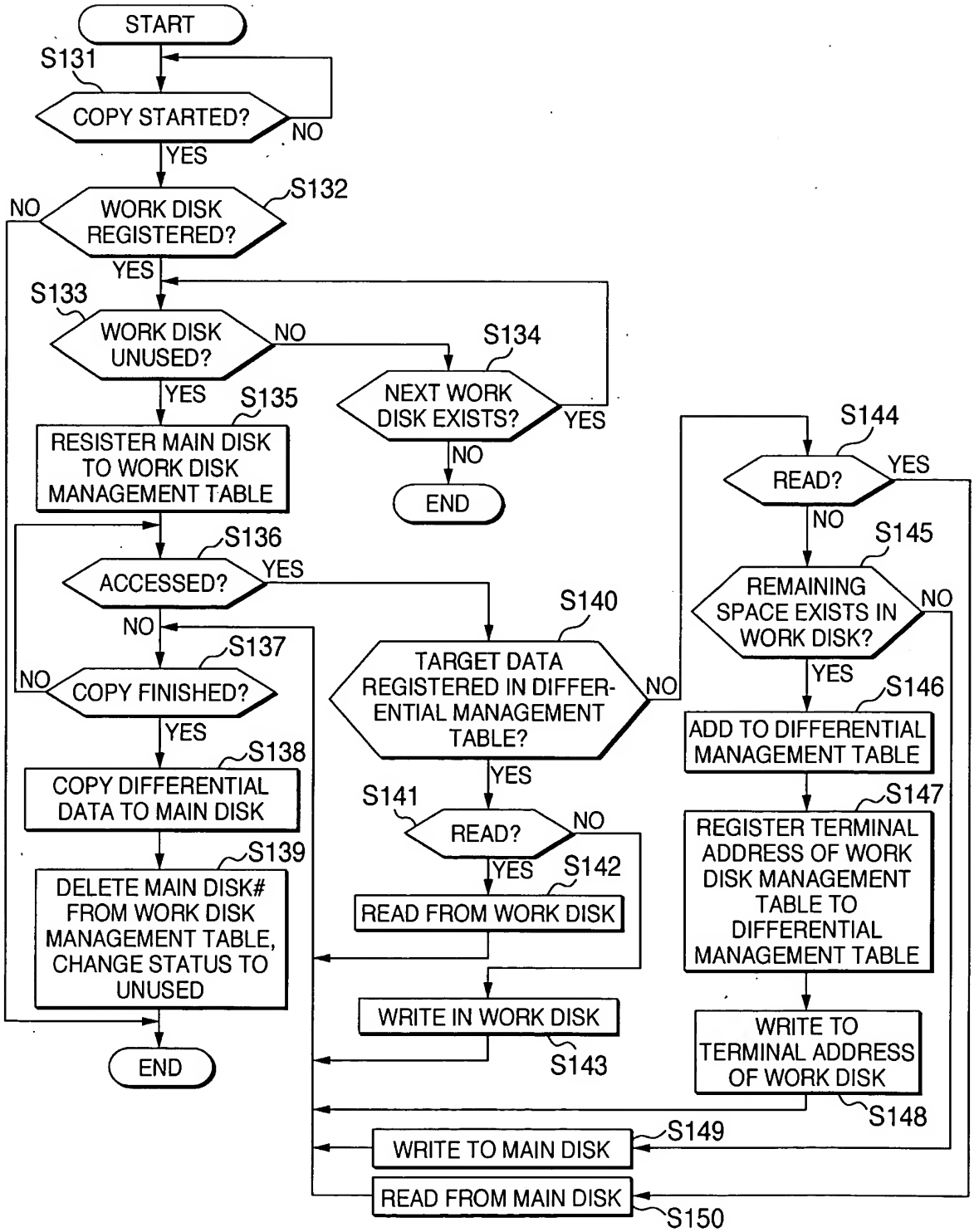
START
S131
COPY STARTED?
NO
YES
S132
NO
WORK DISK REGISTERED?
YES
S133
WORK DISK UNUSED?
NO
S134
NEXT WORK DISK EXISTS?
YES
NO
END
YES
S135
RESISTER MAIN DISK TO WORK DISK MANAGEMENT TABLE
S136
ACCESSED?
YES
NO
S137
NO
COPY FINISHED?
YES
S138
COPY DIFFERENTIAL DATA TO MAIN DISK
S139
DELETE MAIN DISK# FROM WORK DISK MANAGEMENT TABLE, CHANGE STATUS TO UNUSED
END
S140
TARGET DATA REGISTERED IN DIFFERENTIAL MANAGEMENT TABLE?
NO
YES
S141
READ?
NO
YES
S142
READ FROM WORK DISK
WRITE IN WORK DISK
S143
S144
READ?
YES
NO
S145
REMAINING SPACE EXISTS IN WORK DISK?
NO
YES
S146
ADD TO DIFFERENTIAL MANAGEMENT TABLE
S147
REGISTER TERMINAL ADDRESS OF WORK DISK MANAGEMENT TABLE TO DIFFERENTIAL MANAGEMENT TABLE
WRITE TO TERMINAL ADDRESS OF WORK DISK
S148
S149
WRITE TO MAIN DISK
READ FROM MAIN DISK
S150

FIG. 18

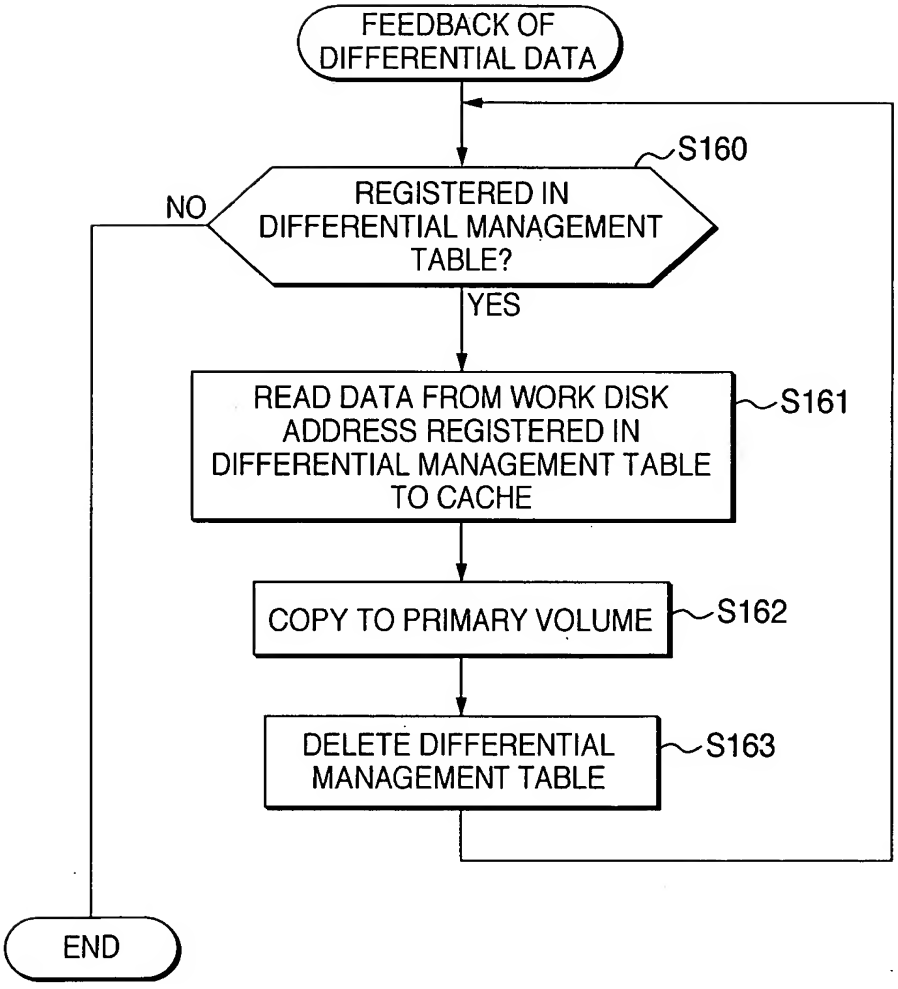
FEEDBACK OF DIFFERENTIAL DATA
S160
REGISTERED IN DIFFERENTIAL MANAGEMENT TABLE?
NO
YES
READ DATA FROM WORK DISK ADDRESS REGISTERED IN DIFFERENTIAL MANAGEMENT TABLE TO CACHE
S161
COPY TO PRIMARY VOLUME
S162
DELETE DIFFERENTIAL MANAGEMENT TABLE
S163
END

FIG. 19

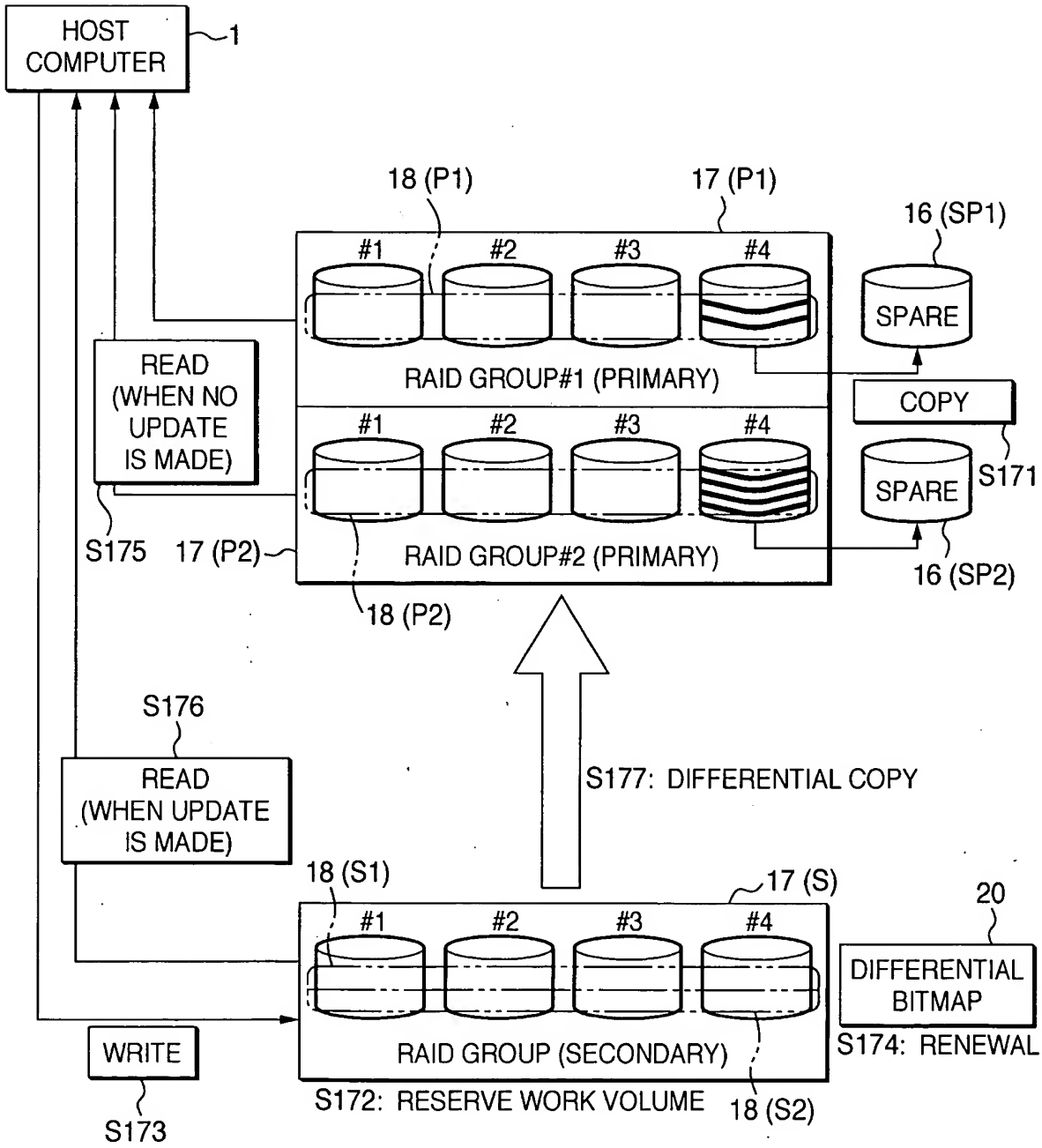
HOST COMPUTER
1
18 (P1)
17 (P1)
16 (SP1)
#1
#2
#3
#4
SPARE
RAID GROUP#1 (PRIMARY)
READ (WHEN NO UPDATE IS MADE)
COPY
S171
#1
#2
#3
#4
SPARE
S175
17 (P2)
RAID GROUP#2 (PRIMARY)
16 (SP2)
18 (P2)
S176
READ (WHEN UPDATE IS MADE)
S177: DIFFERENTIAL COPY
18 (S1)
17 (S)
20
#1
#2
#3
#4
DIFFERENTIAL BITMAP
RAID GROUP (SECONDARY)
S174: RENEWAL
WRITE
S172: RESERVE WORK VOLUME
18 (S2)
S173

FIG. 20A

T4

WORK VOLUME #	CAPACITY	MAIN VOLUME #	TERMINAL ADDRESS	DIFFERENTIAL BITMAP
10	3GB	1, 4	3	1110000000···
11	3GB	2, 5	NULL	0000000000···
12	3GB	3, 6	NULL	0000000000···

FIG. 20B

T6

DISK#	CAPACITY	STATUS	MAIN DISK#	TERMINAL ADDRESS
60	18GB	IN USE	1, 2, 3, 4, 5, 6, 7, 8	6
61	18GB	UNUSED	NULL	NULLL

FIG. 21

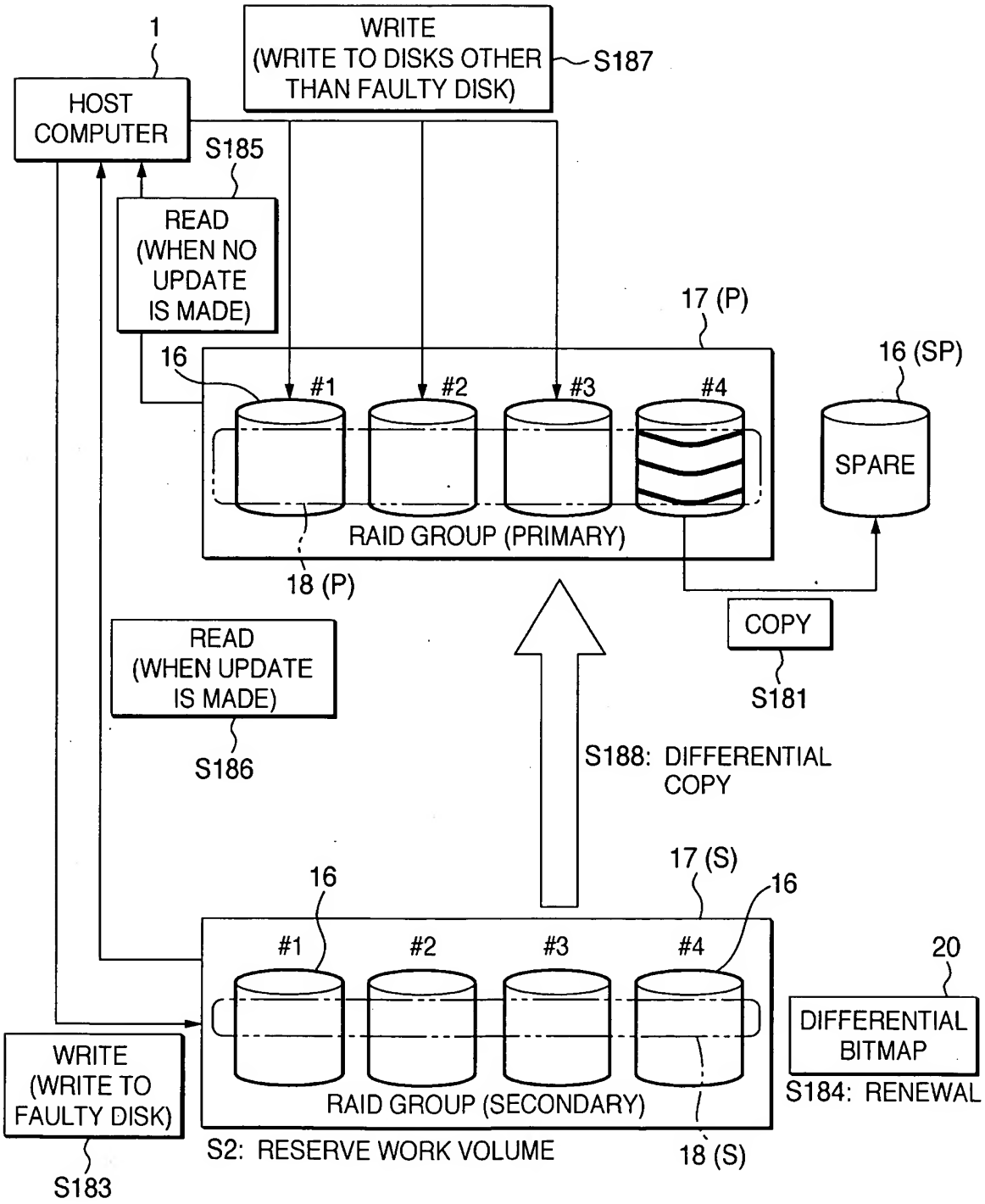
1
HOST COMPUTER
WRITE (WRITE TO DISKS OTHER THAN FAULTY DISK)
S187
S185
READ (WHEN NO UPDATE IS MADE)
17 (P)
16
#1
#2
#3
#4
16 (SP)
SPARE
RAID GROUP (PRIMARY)
18 (P)
COPY
S181
READ (WHEN UPDATE IS MADE)
S186
S188: DIFFERENTIAL COPY
17 (S)
16
16
#1
#2
#3
#4
20
DIFFERENTIAL BITMAP
S184: RENEWAL
WRITE (WRITE TO FAULTY DISK)
RAID GROUP (SECONDARY)
S2: RESERVE WORK VOLUME
18 (S)
S183

FIG. 22

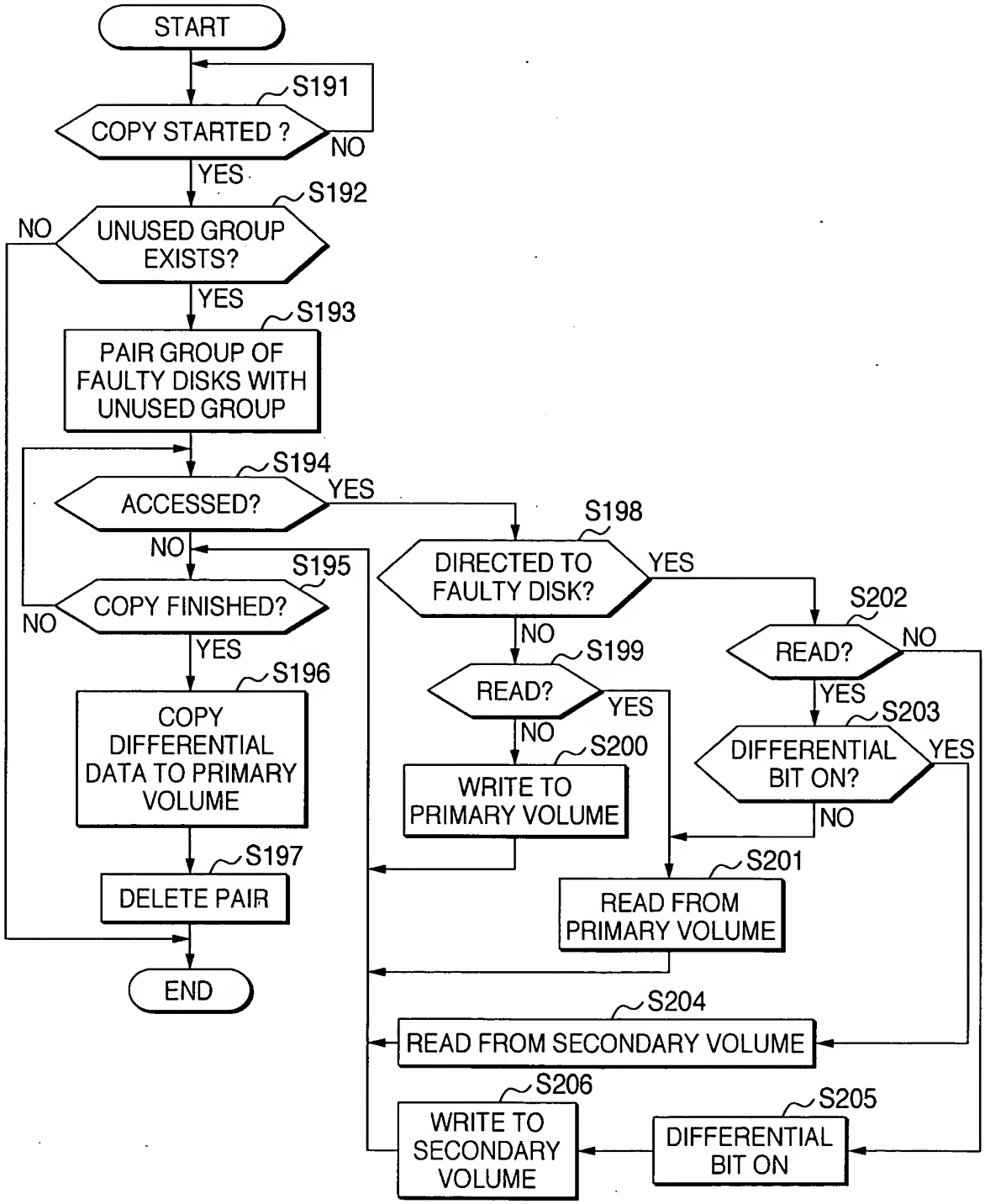
START
S191
COPY STARTED ?
NO
YES
S192
NO
UNUSED GROUP EXISTS?
YES
S193
PAIR GROUP OF FAULTY DISKS WITH UNUSED GROUP
S194
ACCESSED?
YES
NO
S195
COPY FINISHED?
NO
YES
S196
COPY DIFFERENTIAL DATA TO PRIMARY VOLUME
S197
DELETE PAIR
END
S198
DIRECTED TO FAULTY DISK?
YES
NO
S199
READ?
YES
NO
S200
WRITE TO PRIMARY VOLUME
S201
READ FROM PRIMARY VOLUME
S202
READ?
NO
YES
S203
DIFFERENTIAL BIT ON?
YES
NO
S204
READ FROM SECONDARY VOLUME
S205
DIFFERENTIAL BIT ON
S206
WRITE TO SECONDARY VOLUME

FIG. 23

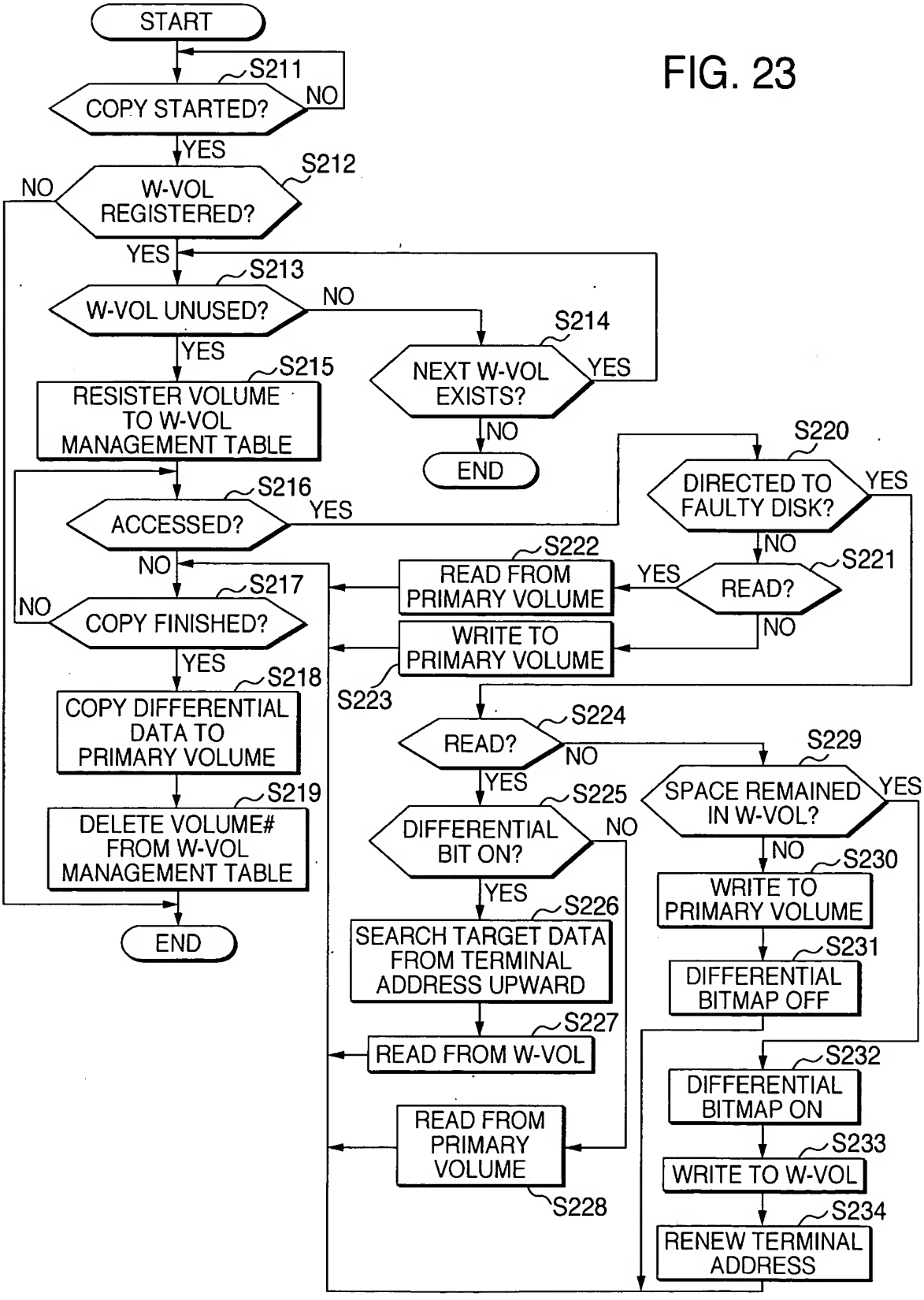
START
S211
COPY STARTED?
NO
YES
S212
W-VOL REGISTERED?
NO
YES
S213
W-VOL UNUSED?
NO
YES
S214
NEXT W-VOL EXISTS?
YES
NO
END
S215
RESISTER VOLUME TO W-VOL MANAGEMENT TABLE
S216
ACCESSED?
YES
NO
S217
COPY FINISHED?
NO
YES
S218
COPY DIFFERENTIAL DATA TO PRIMARY VOLUME
S219
DELETE VOLUME# FROM W-VOL MANAGEMENT TABLE
END
S220
DIRECTED TO FAULTY DISK?
YES
NO
S221
READ?
YES
NO
S222
READ FROM PRIMARY VOLUME
WRITE TO PRIMARY VOLUME
S223
S224
READ?
NO
YES
S225
DIFFERENTIAL BIT ON?
NO
YES
S226
SEARCH TARGET DATA FROM TERMINAL ADDRESS UPWARD
S227
READ FROM W-VOL
READ FROM PRIMARY VOLUME
S228
S229
SPACE REMAINED IN W-VOL?
YES
NO
S230
WRITE TO PRIMARY VOLUME
S231
DIFFERENTIAL BITMAP OFF
S232
DIFFERENTIAL BITMAP ON
S233
WRITE TO W-VOL
S234
RENEW TERMINAL ADDRESS

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FIG. 24

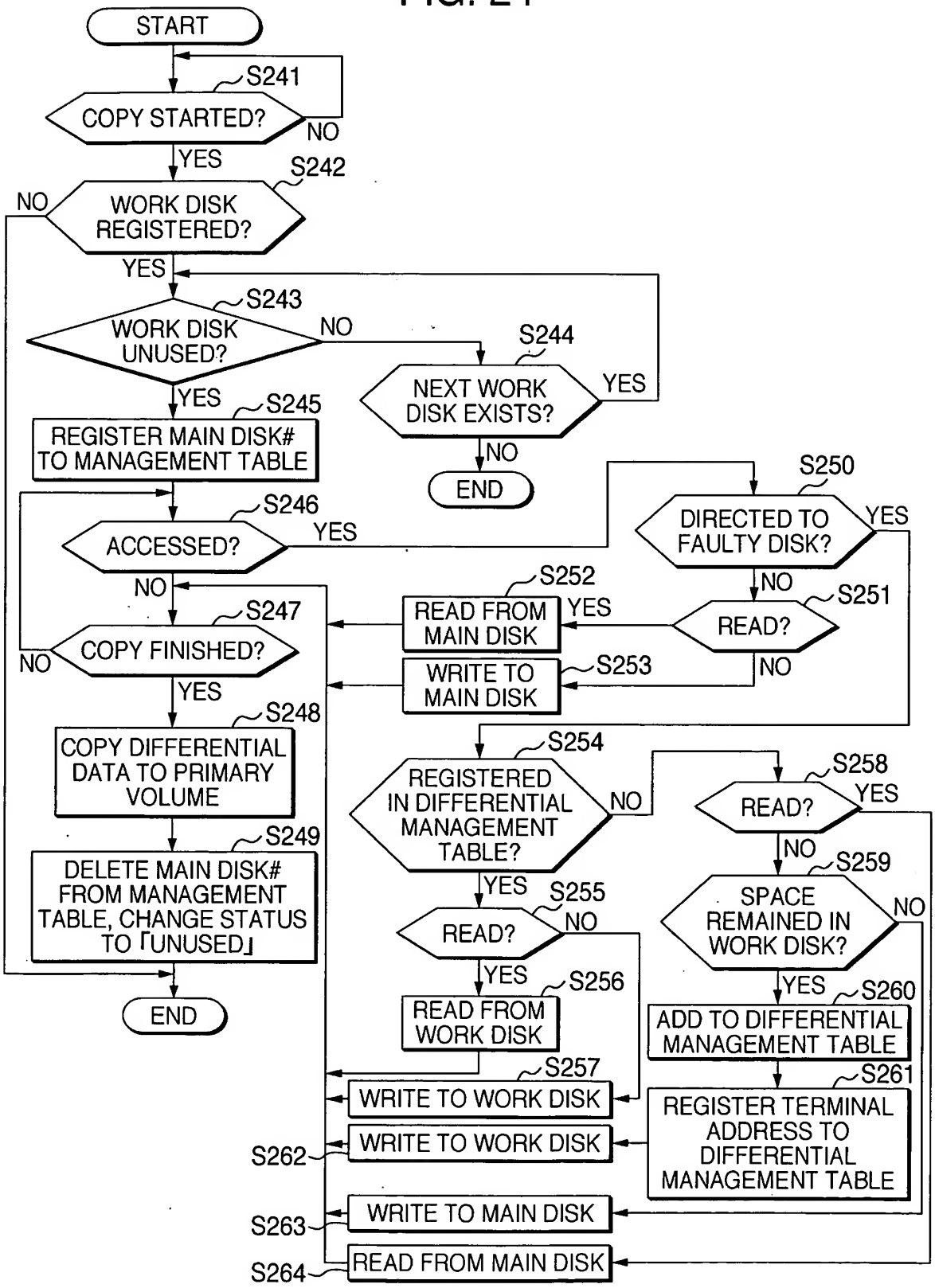
START
S241
COPY STARTED?
NO
YES
S242
NO
WORK DISK REGISTERED?
YES
S243
WORK DISK UNUSED?
NO
S244
NEXT WORK DISK EXISTS?
YES
NO
END
YES
S245
REGISTER MAIN DISK# TO MANAGEMENT TABLE
S246
ACCESSED?
YES
NO
S247
COPY FINISHED?
NO
YES
S248
COPY DIFFERENTIAL DATA TO PRIMARY VOLUME
S249
DELETE MAIN DISK# FROM MANAGEMENT TABLE, CHANGE STATUS TO 「UNUSED」
END
S250
DIRECTED TO FAULTY DISK?
YES
NO
S251
READ?
YES
NO
S252
READ FROM MAIN DISK
S253
WRITE TO MAIN DISK
S254
REGISTERED IN DIFFERENTIAL MANAGEMENT TABLE?
NO
YES
S255
READ?
NO
YES
S256
READ FROM WORK DISK
S257
WRITE TO WORK DISK
S262
WRITE TO WORK DISK
S263
WRITE TO MAIN DISK
S264
READ FROM MAIN DISK
S258
READ?
YES
NO
S259
SPACE REMAINED IN WORK DISK?
NO
YES
S260
ADD TO DIFFERENTIAL MANAGEMENT TABLE
S261
REGISTER TERMINAL ADDRESS TO DIFFERENTIAL MANAGEMENT TABLE

FIG. 25

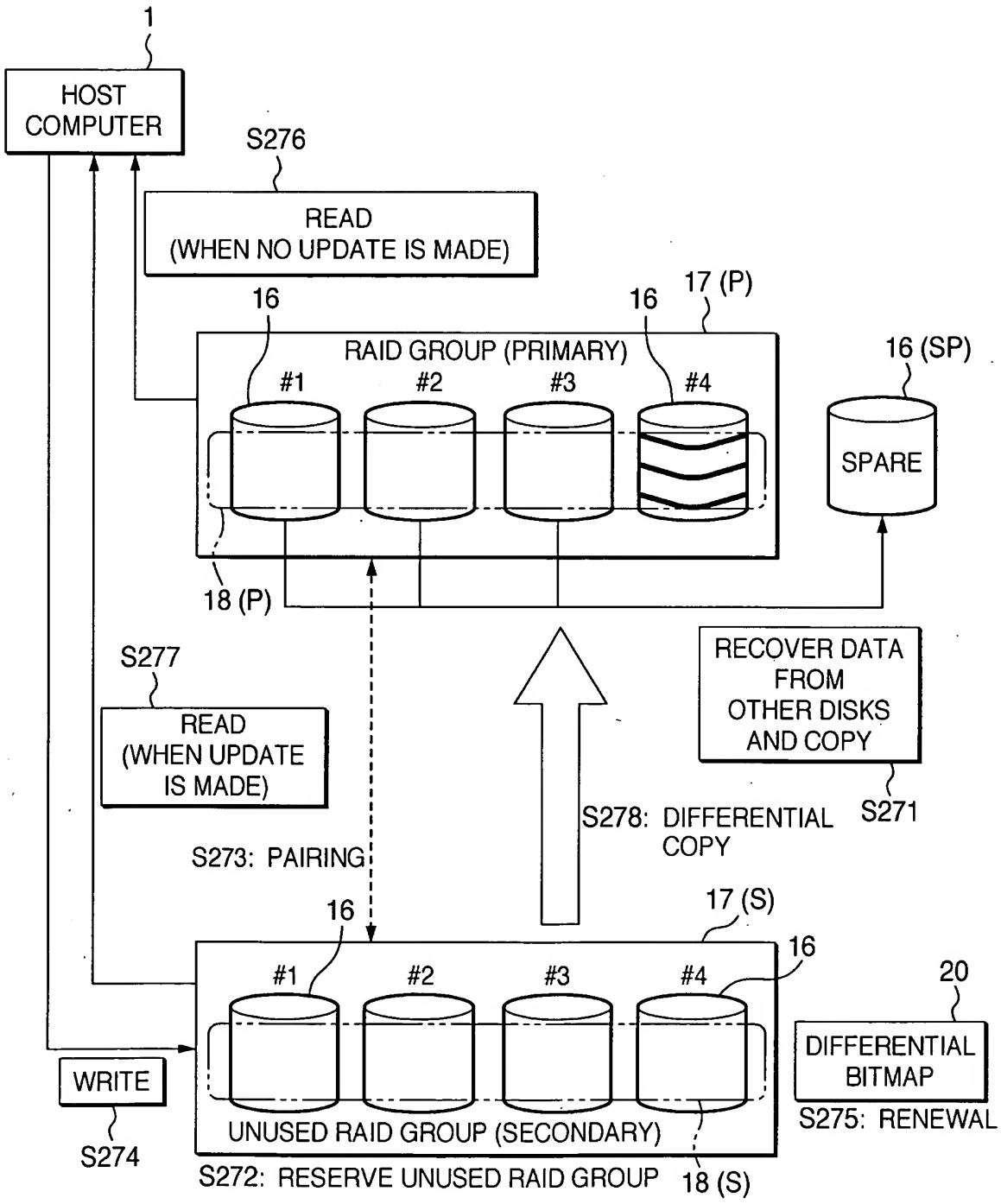
1
HOST COMPUTER
S276
READ (WHEN NO UPDATE IS MADE)
16
16
17 (P)
RAID GROUP (PRIMARY)
#1
#2
#3
#4
16 (SP)
SPARE
18 (P)
S277
READ (WHEN UPDATE IS MADE)
RECOVER DATA FROM OTHER DISKS AND COPY
S271
S278: DIFFERENTIAL COPY
S273: PAIRING
16
17 (S)
16
#1
#2
#3
#4
20
DIFFERENTIAL BITMAP
S275: RENEWAL
WRITE
S274
UNUSED RAID GROUP (SECONDARY)
S272: RESERVE UNUSED RAID GROUP
18 (S)

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FIG. 26

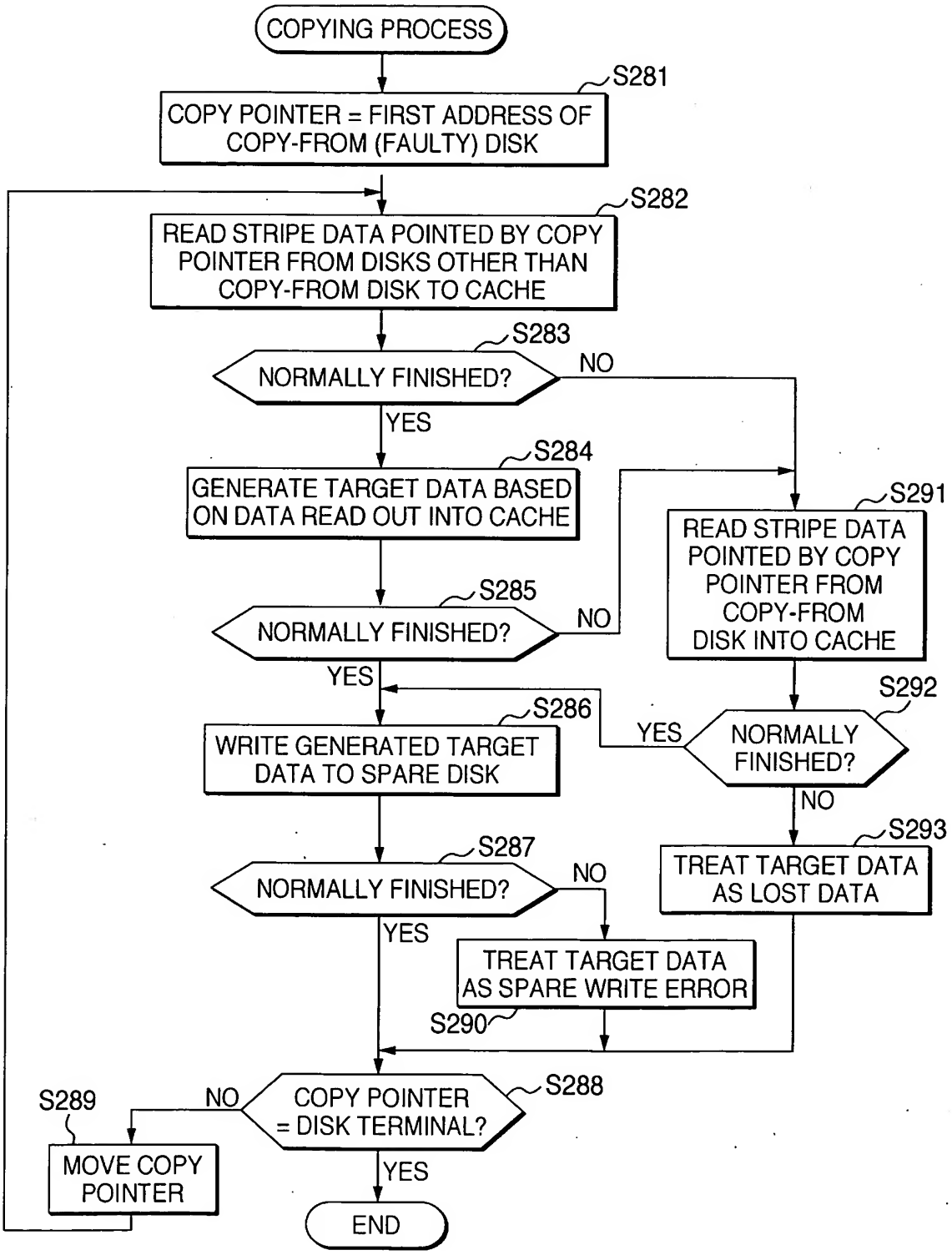

COPYING PROCESS
S281
COPY POINTER = FIRST ADDRESS OF COPY-FROM (FAULTY) DISK
S282
READ STRIPE DATA POINTED BY COPY POINTER FROM DISKS OTHER THAN COPY-FROM DISK TO CACHE
S283
NORMALLY FINISHED?
NO
YES
S284
GENERATE TARGET DATA BASED ON DATA READ OUT INTO CACHE
S285
NORMALLY FINISHED?
NO
YES
S286
WRITE GENERATED TARGET DATA TO SPARE DISK
S287
NORMALLY FINISHED?
NO
YES
TREAT TARGET DATA AS SPARE WRITE ERROR
S290
S291
READ STRIPE DATA POINTED BY COPY POINTER FROM COPY-FROM DISK INTO CACHE
S292
NORMALLY FINISHED?
YES
NO
S293
TREAT TARGET DATA AS LOST DATA
S288
COPY POINTER = DISK TERMINAL?
NO
YES
S289
MOVE COPY POINTER
END

FIG. 27

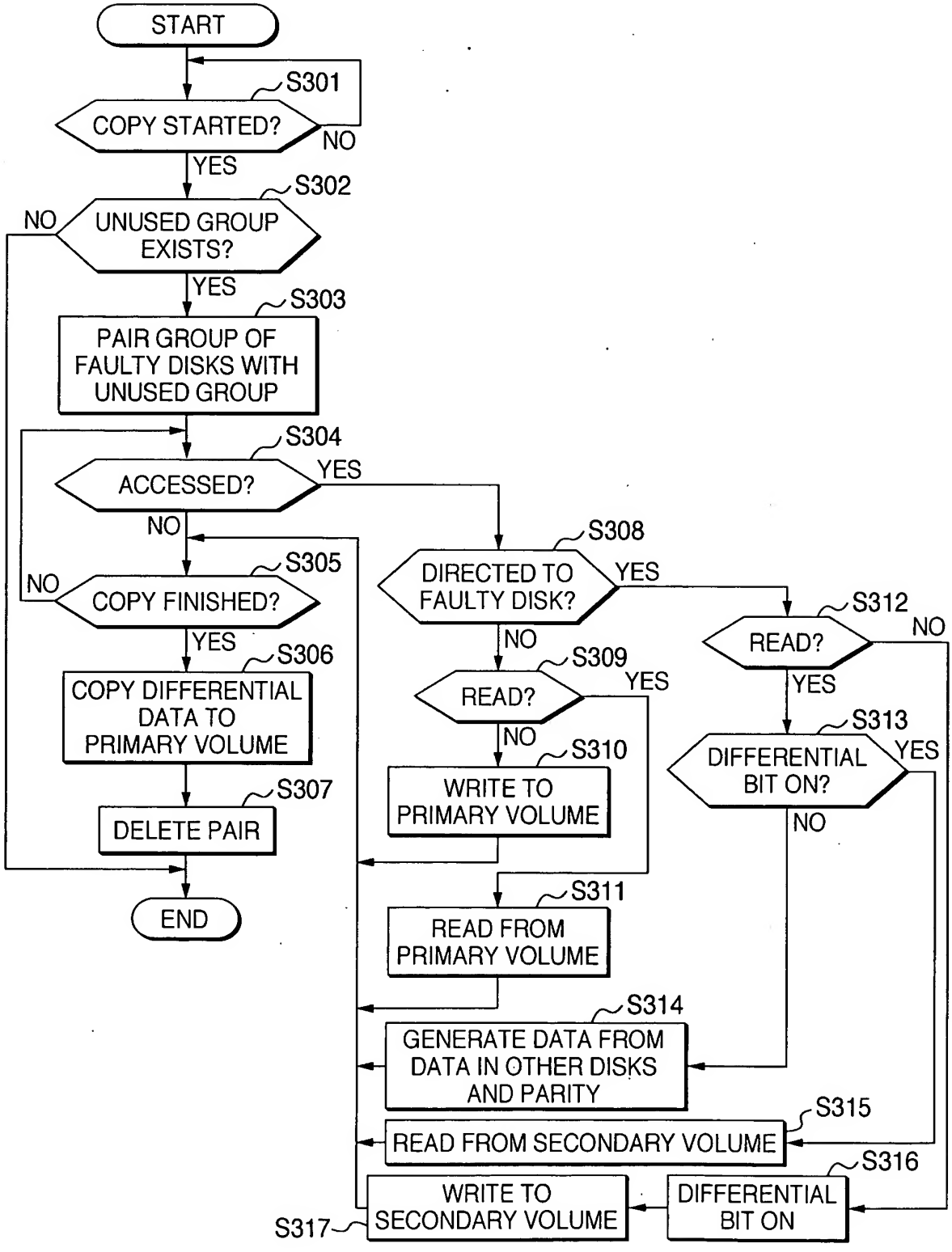

START
S301
COPY STARTED?
NO
YES
S302
NO
UNUSED GROUP EXISTS?
YES
S303
PAIR GROUP OF FAULTY DISKS WITH UNUSED GROUP
S304
ACCESSED?
YES
NO
S305
NO
COPY FINISHED?
YES
S306
COPY DIFFERENTIAL DATA TO PRIMARY VOLUME
S307
DELETE PAIR
END
S308
DIRECTED TO FAULTY DISK?
YES
NO
S309
READ?
YES
NO
S310
WRITE TO PRIMARY VOLUME
S311
READ FROM PRIMARY VOLUME
S312
READ?
NO
YES
S313
DIFFERENTIAL BIT ON?
YES
NO
S314
GENERATE DATA FROM DATA IN OTHER DISKS AND PARITY
S315
READ FROM SECONDARY VOLUME
S316
DIFFERENTIAL BIT ON
WRITE TO SECONDARY VOLUME
S317

FIG. 28

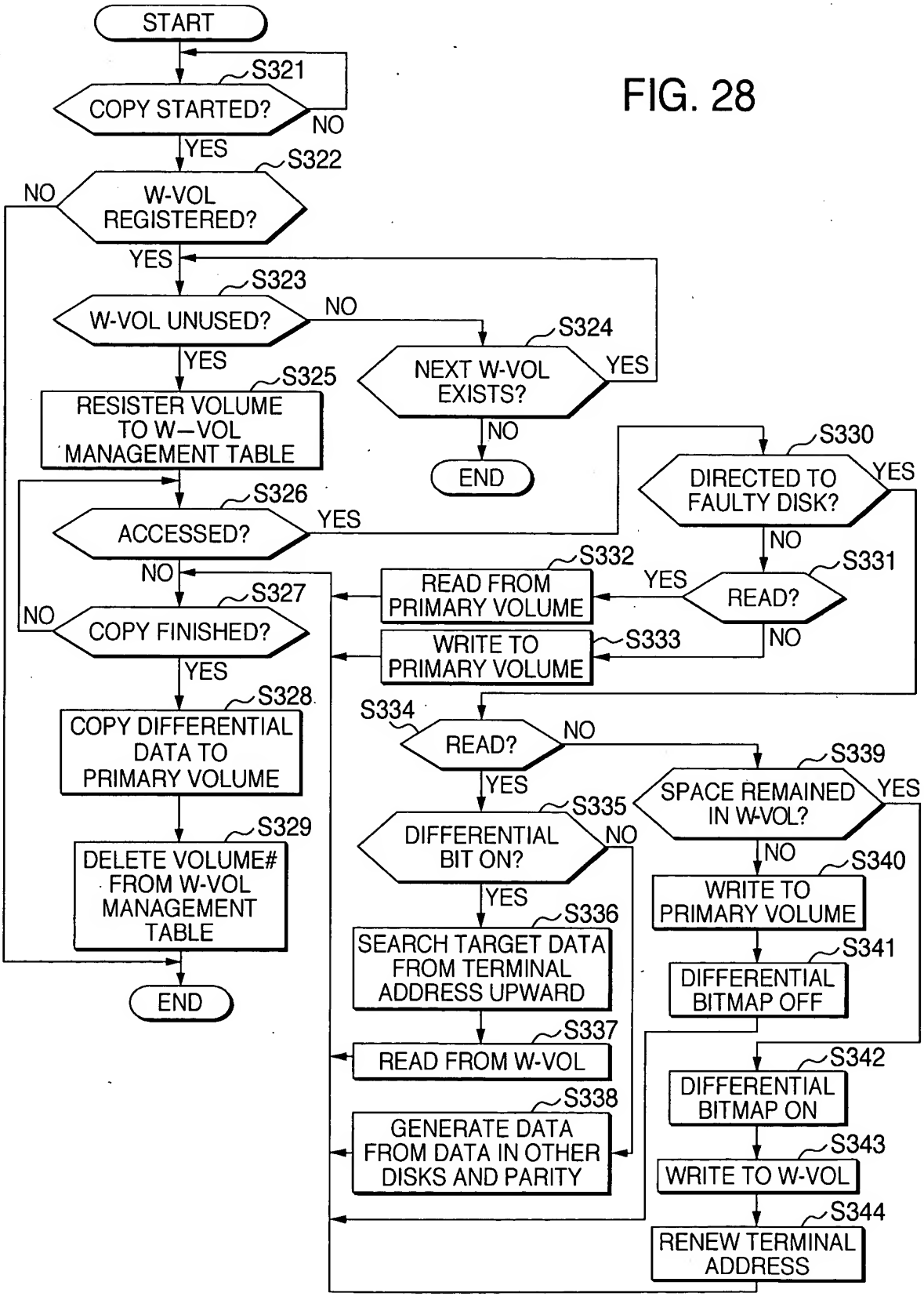
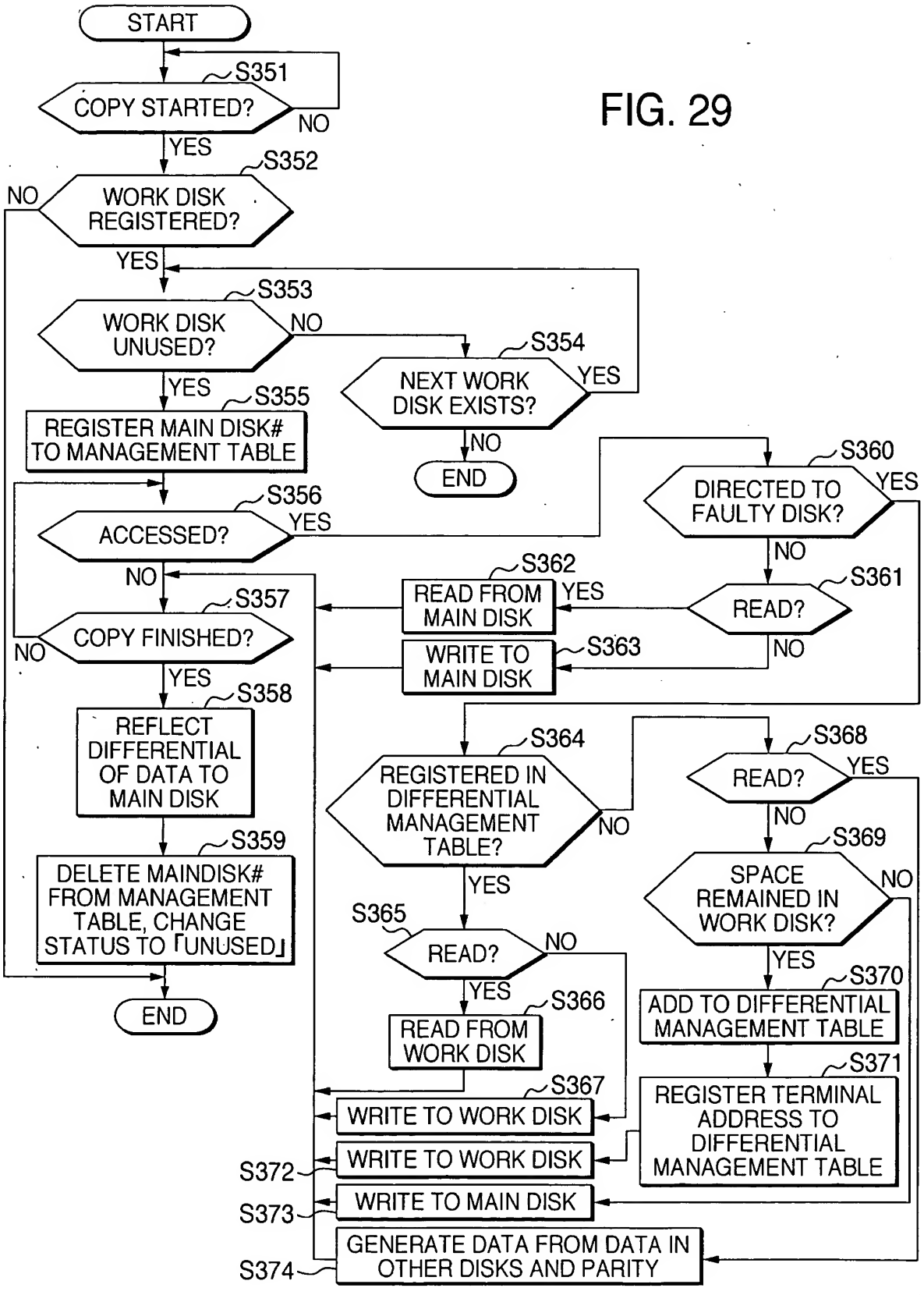

START
S321
COPY STARTED?
NO
YES
S322
W-VOL REGISTERED?
NO
YES
S323
W-VOL UNUSED?
NO
YES
S324
NEXT W-VOL EXISTS?
YES
NO
END
S325
RESISTER VOLUME TO W—VOL MANAGEMENT TABLE
S326
ACCESSED?
YES
NO
S327
COPY FINISHED?
NO
YES
S328
COPY DIFFERENTIAL DATA TO PRIMARY VOLUME
S329
DELETE VOLUME# FROM W-VOL MANAGEMENT TABLE
END
S330
DIRECTED TO FAULTY DISK?
YES
NO
S331
READ?
YES
NO
S332
READ FROM PRIMARY VOLUME
S333
WRITE TO PRIMARY VOLUME
S334
READ?
NO
YES
S335
DIFFERENTIAL BIT ON?
NO
YES
S336
SEARCH TARGET DATA FROM TERMINAL ADDRESS UPWARD
S337
READ FROM W-VOL
S338
GENERATE DATA FROM DATA IN OTHER DISKS AND PARITY
S339
SPACE REMAINED IN W-VOL?
YES
NO
S340
WRITE TO PRIMARY VOLUME
S341
DIFFERENTIAL BITMAP OFF
S342
DIFFERENTIAL BITMAP ON
S343
WRITE TO W-VOL
S344
RENEW TERMINAL ADDRESS

FIG. 29


START
S351
COPY STARTED?
NO
YES
S352
NO
WORK DISK REGISTERED?
YES
S353
WORK DISK UNUSED?
NO
S354
NEXT WORK DISK EXISTS?
YES
NO
END
YES
S355
REGISTER MAIN DISK# TO MANAGEMENT TABLE
S356
ACCESSED?
YES
NO
S357
COPY FINISHED?
NO
YES
S358
REFLECT DIFFERENTIAL OF DATA TO MAIN DISK
S359
DELETE MAINDISK# FROM MANAGEMENT TABLE, CHANGE STATUS TO 「UNUSED」
END
S360
DIRECTED TO FAULTY DISK?
YES
NO
S361
READ?
YES
NO
S362
READ FROM MAIN DISK
S363
WRITE TO MAIN DISK
S364
REGISTERED IN DIFFERENTIAL MANAGEMENT TABLE?
NO
YES
S365
READ?
NO
YES
S366
READ FROM WORK DISK
S367
WRITE TO WORK DISK
S372
WRITE TO WORK DISK
S373
WRITE TO MAIN DISK
S374
GENERATE DATA FROM DATA IN OTHER DISKS AND PARITY
S368
READ?
YES
NO
S369
SPACE REMAINED IN WORK DISK?
NO
YES
S370
ADD TO DIFFERENTIAL MANAGEMENT TABLE
S371
REGISTER TERMINAL ADDRESS TO DIFFERENTIAL MANAGEMENT TABLE